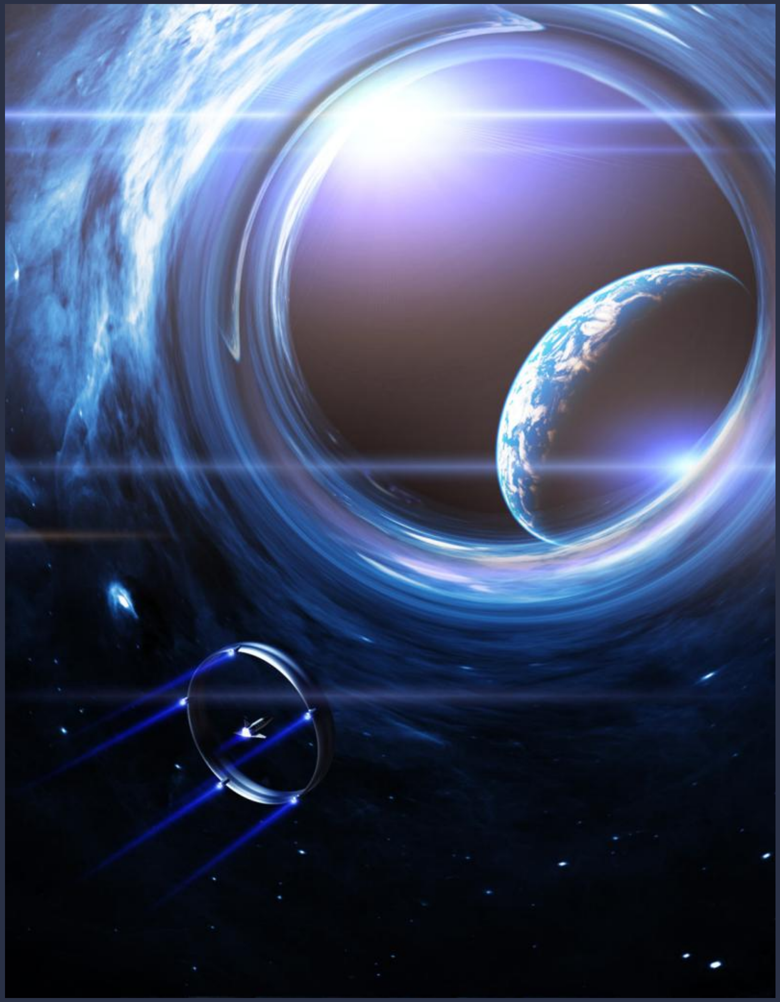
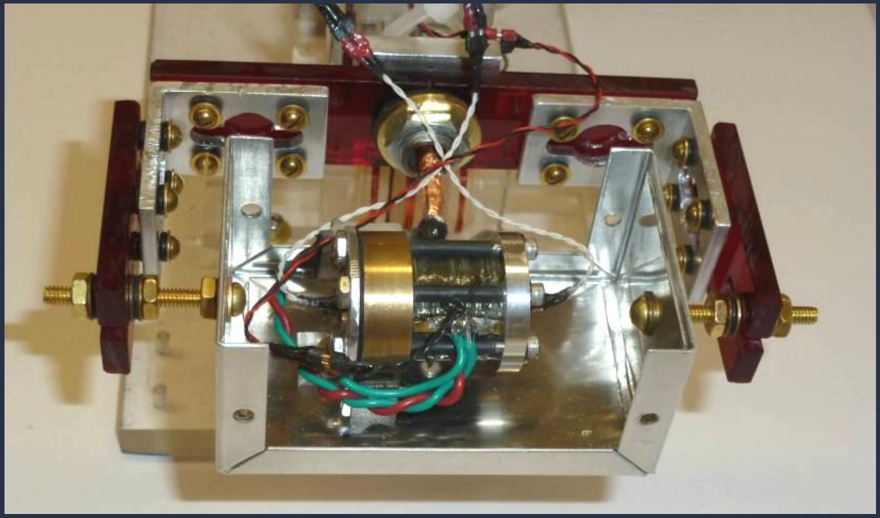
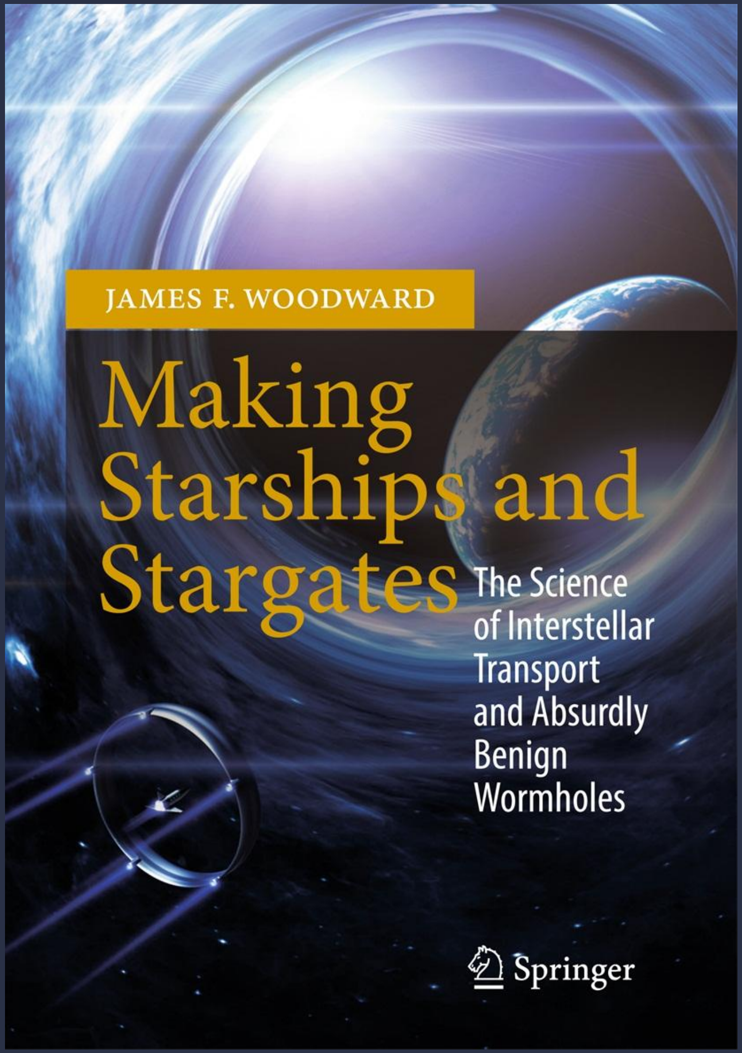
Recent Theory & Experimental work on Mach Effect Thrusters



Prof. Heidi Fearn
Cal. State Fullerton.



A call to arms…



Comes out in Dec 2012.
It's a great read and all proceeds go to charity
Or to space propulsion research such as this!
www.ssi.org

Mach effect drive is an IMPULSE Drive… not warp- drive.

Mach's Principle:

The inertial mass of a body is determined by the distribution and flow of mass-energy in the universe. (see arXiv)

Ernest Mach 1872 rejected the existence of absolute space in favor of relative motion with respect to a "fixed frame" provided by the matter distribution in the universe.

E. Mach "The science of Mechanics – A critical Historical account of its Development," (Open Court, LA Salle , 1960.)

In 1953 Dennis Sciama [1]
the "gravelectric" field is given by:

$$\mathbf{E}_g = -\nabla\phi - \frac{1}{c}\frac{\partial \mathbf{A}_g}{\partial t}$$

where $\mathbf{E}_g$ is the gravelectric field strength, F_g/m and Φ and $\mathbf{A}_g$ are the scalar and three-vector potentials of the field.

This A_g is fully consistent with the modified PPN approx, where a Lorentz transformation is used on the flat space-time metric, Nordvedt [2,7], Sultana & Kazanas [3], Cook [4].

$$\mathbf{A}_g = \frac{G}{c}\int_V \frac{\rho\mathbf{v}}{r}\,dV = \frac{1}{c}\phi\,\mathbf{v}$$

where *ρ* is the "matter" density, **v** the velocity of the matter in the integration volume element, *r* the distance to the volume element, and the integration extends over all space.

Consistent with LW potentials in SR. (Sciama used Φ/G).

$$\phi = \frac{GM}{R}$$

where G is Newton's constant of gravitation, *M* the mass of the universe, and *R* (= *ct*) is the radius of the "Hubble sphere". The equation for the gravelectric field thus is:

$$\frac{F_g}{m} = \mathbf{E}_g = -\nabla\phi - \frac{\phi}{c^2}\frac{\partial \mathbf{v}}{\partial t} = -\nabla\phi - \frac{GM}{Rc^2}\frac{\partial \mathbf{v}}{\partial t}$$

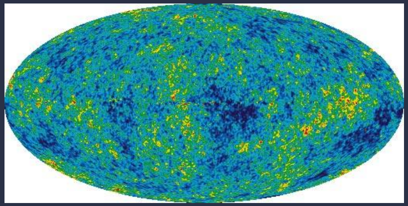
The fact that inertial reaction forces are independent of time and place requires that the masses of things be equal to their total gravitational potential energies.

$$E = mc^2$$

$$\varepsilon_g = m_g \phi$$

$$E = \varepsilon_g \Rightarrow m = m_g$$

$$\phi = c^2$$



Sciama's calculation is a vector approximation to general relativity done for idealized situation.

Is this true for a general relativistic calculation using realistic cosmological parameters? [3]

Factor 4 missing Nordvedt [2]. Yes.

F=0.23ma, fixed F= 0.92ma !

no gravity forces, [4 cook],
"frame dragging" [6]

[3] Sultana, J. and Kazanas, D. "The problem of inertia in Friedmann Universe", 2011, arXiv: 1104.1306v.
[6] Pascual-Sanchez, J-F. "The harmonic gauge condition in the gravitomagnetic equations" arXiv: gr-qc/0010075v1

Is Φ, like c, in fact a locally measured invariant – required if inertial forces are due exclusively to gravity?

Definition of geodesic gives you the force/m! (g_{0i} Nordtvedt)

$$F = \frac{GMma}{c^2 R} = \frac{Gm}{c^2}\int \frac{\rho(r)a(r)}{|r_m - r|}d^3r$$

$$\frac{F^\mu}{m} = -\Gamma^\mu_{\alpha\beta}\upsilon^\alpha\upsilon^\beta = \frac{d^2x^\mu}{d\tau^2}$$

YES. This was shown by Carl Brans [8] in 1960's If not q/m ratios of elementary particles would vary, depending on the local gravity field present. NO such variation is observed!

Inertial forces are due to gravity… so what?

In analogy with electrodynamics where the force per unit charge is given by the electric field, and

$$\text{Div } E = 4\pi\rho$$

where ρ is the charge per unit vol. in Gaussian units.

4-force/mass

$$F^{\mu} = -\left(\frac{c}{\rho_o}\frac{\partial\rho_o}{\partial t}, E_g\right)$$

The Divergence of the force/mass for the gravitational field Is given by ,

$$\partial_{\mu}F^{\mu} = 4\pi G\rho$$

where ρ is mass per unit vol. (metric - +++). Expanding…

More math than you wanted to see...

$$-\frac{1}{c^2}\frac{\partial}{\partial t}\left(\frac{1}{\rho_o}\frac{\partial E_o}{\partial t}\right)-\nabla\cdot E_g=4\pi G\rho$$

where E_o is energy density and $E_o = \rho_o c^2$

$$-\frac{1}{\rho_o c^2}\frac{\partial^2 E_o}{\partial t^2}+\left(\frac{1}{\rho_o c^2}\right)^2\left(\frac{\partial E_o}{\partial t}\right)^2-\nabla\cdot E_g=4\pi G\rho$$

$$-\nabla\cdot E_g=\nabla^2\phi$$

$$E_o=\rho_o\phi$$

$$-\frac{1}{\rho_o c^2}\frac{\partial^2 E_o}{\partial t^2}=\frac{1}{c^2}\frac{\partial^2\phi}{\partial t^2}-\frac{2}{\rho_o c^2}\frac{\partial\phi}{\partial t}\frac{\partial\rho_o}{\partial t}-\frac{\phi}{\rho_o c^2}\frac{\partial^2\rho_o}{\partial t^2}$$

$$\nabla^2\phi - \frac{1}{c^2}\frac{\partial^2\phi}{\partial t^2} - \frac{2}{\rho_o c^2}\frac{\partial\phi}{\partial t}\frac{\partial\rho_o}{\partial t} - \frac{\phi}{\rho_o c^2}\frac{\partial^2\rho_o}{\partial t^2} + \left(\frac{1}{\rho_o c^2}\right)^2\left(\frac{\partial E_o}{\partial t}\right)^2 = 4\pi G\rho$$

$$E_o = \rho_o c^2$$

$$\left(\frac{1}{\rho_o c^2}\right)^2\left(\frac{\partial E_o}{\partial t}\right)^2 = \left(\frac{1}{\rho_o c^2}\right)^2\left(\rho_o\frac{\partial\phi}{\partial t} + \phi\frac{\partial\rho_o}{\partial t}\right)^2 =$$

$$\frac{1}{c^4}\left(\frac{\partial\phi}{\partial t}\right)^2 + \frac{2\phi}{\rho_o c^4}\frac{\partial\phi}{\partial t}\frac{\partial\rho_o}{\partial t} + \left(\frac{\phi}{\rho_o c^2}\right)^2\left(\frac{\partial\rho_o}{\partial t}\right)^2$$

$$\nabla^2\phi - \frac{1}{c^2}\frac{\partial^2\phi}{\partial t^2} = 4\pi G\rho + \frac{\phi}{\rho_o c^2}\frac{\partial^2\rho_o}{\partial t^2} - \left(\frac{\phi}{\rho_o c^2}\right)^2\left(\frac{\partial\rho_o}{\partial t}\right)^2 - \cancel{\frac{1}{c^4}\left(\frac{\partial\phi}{\partial t}\right)^2}$$

Note the transient terms on the RHS of the eqn.

Last of the math!

$$\delta\rho_o(t) \approx \frac{1}{4\pi G}\left[\frac{\phi}{\rho_o c^4}\frac{\partial^2 E_o}{\partial t^2} - \left(\frac{\phi}{\rho_o c^4}\right)^2\left(\frac{\partial E_o}{\partial t}\right)^2\right]$$

$$\phi = c^2$$

$$\delta\rho_o(t) \approx \frac{1}{4\pi G}\left[\frac{1}{\rho_o c^2}\frac{\partial^2 E_o}{\partial t^2} - \left(\frac{1}{\rho_o c^2}\right)^2\left(\frac{\partial E_o}{\partial t}\right)^2\right]$$

$$\rho_o = m_o / V$$

$$E_o = \varepsilon / V$$

$$\frac{\partial \varepsilon}{\partial t} = P$$

$$\frac{\delta m_o(t)}{V} \approx \frac{1}{4\pi G}\left[\frac{1}{\rho_o V c^2}\frac{\partial^2 \varepsilon}{\partial t^2} - \left(\frac{1}{\rho_o c^2 V}\right)^2\left(\frac{\partial \varepsilon}{\partial t}\right)^2\right]$$

thus can write δm in terms of Power P…

THE "MACH EFFECT" EQUATION

QUANTIFIES THE MAGNITUDE OF THE PREDICTED MASS FLUCTUATIONS IN ACCELERATED OBJECTS:

$$\delta m_0 \approx \frac{1}{4\pi G}\left[\boxed{\frac{1}{\rho_0 c^2}\frac{\partial P}{\partial t}} - \boxed{\left(\frac{1}{\rho_0 c^2}\right)^2 \frac{P^2}{V}}\right]$$

- The linear term in *P* [the power delivered to a capacitor] is the "impulse engine" term.
- The quadratic term in *P* is the "wormhole" term (because it is always negative), normally a factor of $1/c^2$ smaller than the impulse engine term.
- Note, however, that this is only true for extended objects under-going "bulk" accelerations.


Campbell Dec 98

The gravitational/inertial effects in question are transients;

fluctuations in the rest-masses of objects accelerated by external forces that undergo changes in their internal energies as they are accelerated.

PZT IS THE ACTIVE MASS, (PIEZO-ELECTRIC EFFECT … V)

THE EXTERNAL FORCE IS CAUSED BY THE ELECTRO-STRICTIVE FORCE IN PZT, GOES AS V^2

The prediction equations (see paper for details [5]):

The Mach effect mass fluctuation written with explicit acceleration dependence:

$$\delta m_0 \approx \frac{1}{4\pi G \rho_0 c^2} \frac{\partial P}{\partial t} \approx \frac{1}{4\pi G \rho_0 c^2} m_0 a^2$$

At resonance:

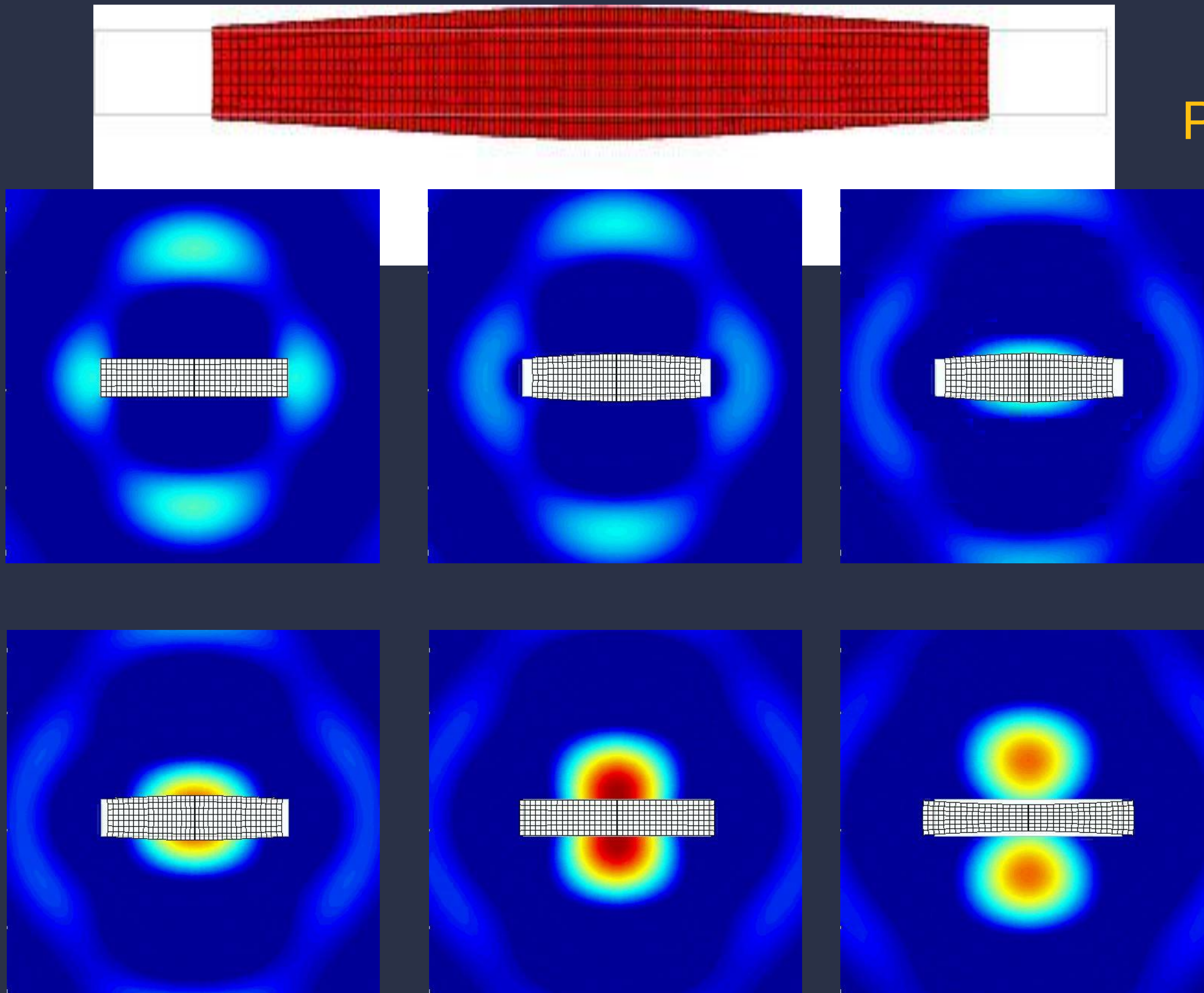
$$i = i_0 \cos \omega t$$

$$V = V_0 \cos \omega t$$

$$\mathbf{F} = \delta m_0 \ddot{x} \approx \frac{\omega^6 m_0 K_p K_e x_0^3 V_0^4}{8\pi G \rho_0 c^2} \left(1 + 2\cos 2\omega t + \cos 4\omega t\right)$$

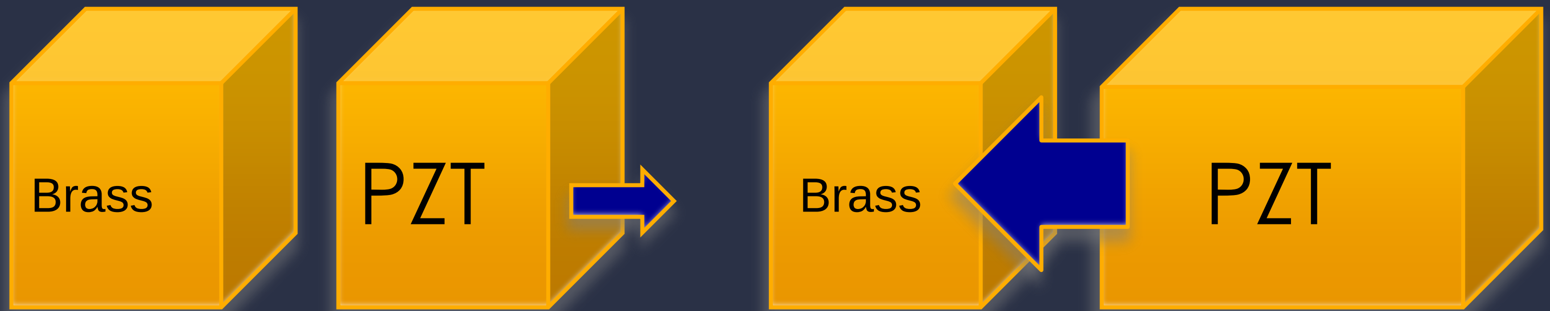
(The calculation is in the paper.)

Vibrational Modes of PZT   http://web.ift.uib.no/~jankoc/thesis/



PZT-A5

What if you can make the mass of a PZT disc fluctuate, and act on it in a direction when it is heavier and in the opposite direction when it is lighter?

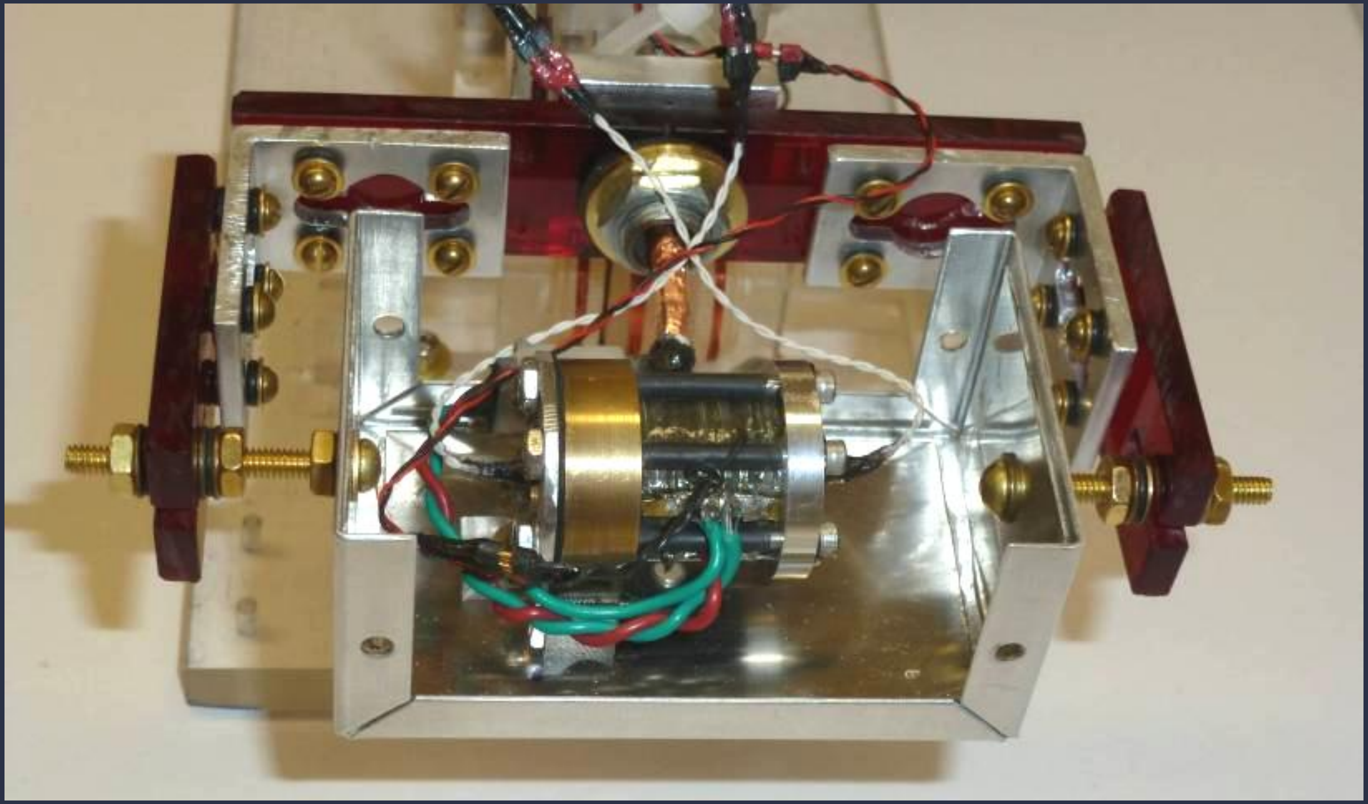


Pull on reaction mass when light.

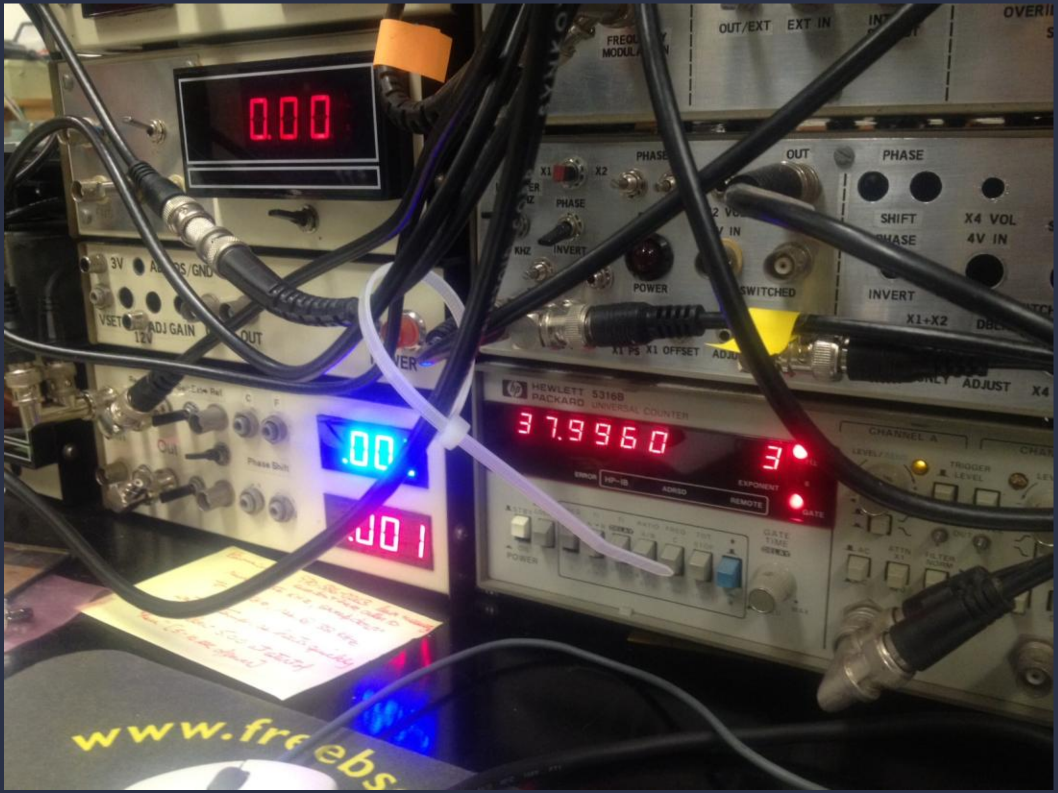
Heavy, push : PZT expanding

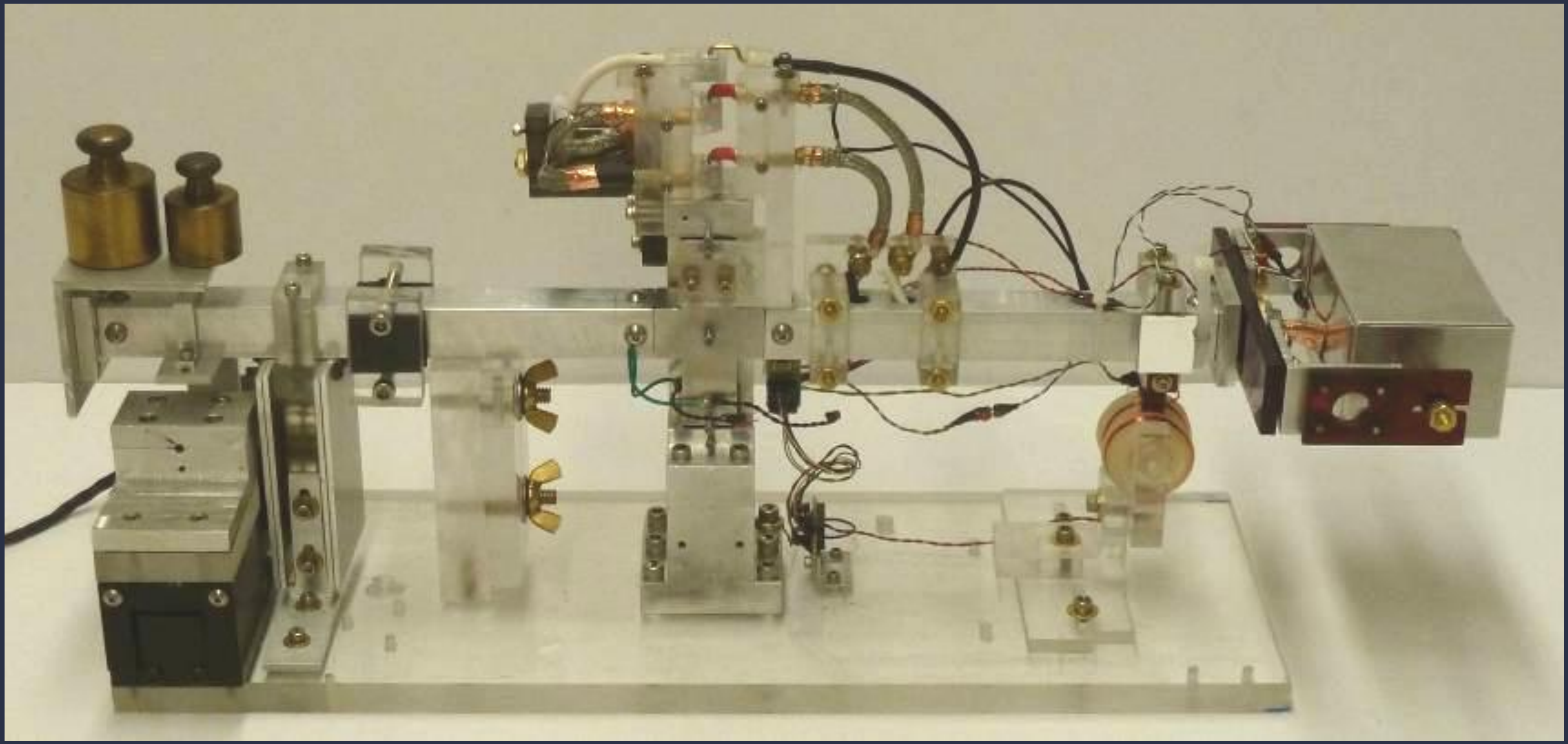
ACCELERATION

Devices to test for the presence of Mach effects



Apparatus and experimental protocols

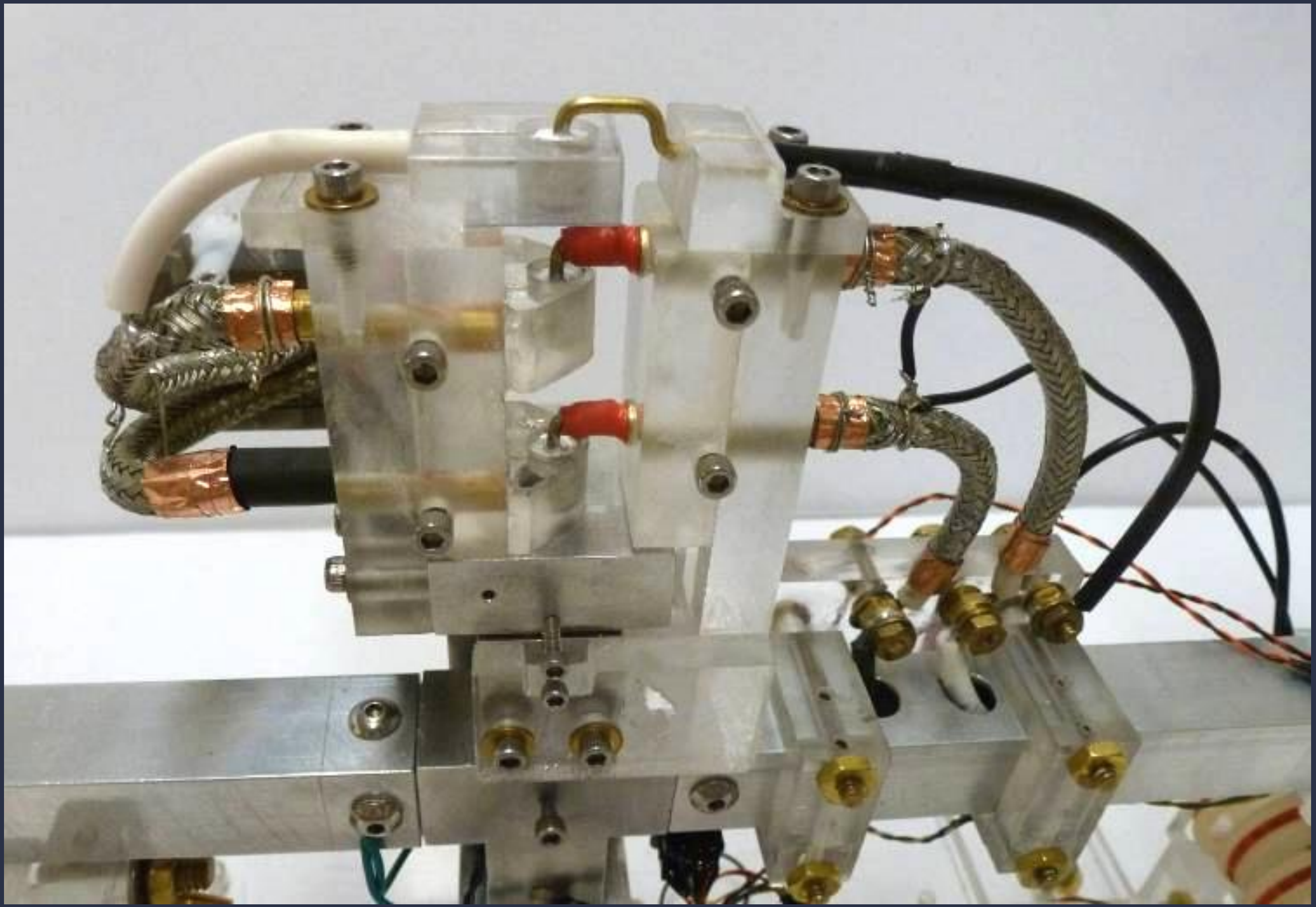




The USC/ARC style thrust balance in its present form.
The balance beam is supported by two flexural bearings in the center column.
The position of the beam is detected with a Philtech optical position sensor.
The test devices are located in the Faraday cage mounted on the right.
Thrust calibration coils are located near the Faraday cage.

C-Flex E-10 flexural bearings.

Two views of one of the flexural bearings that support the thrust balance Beam in the central column.



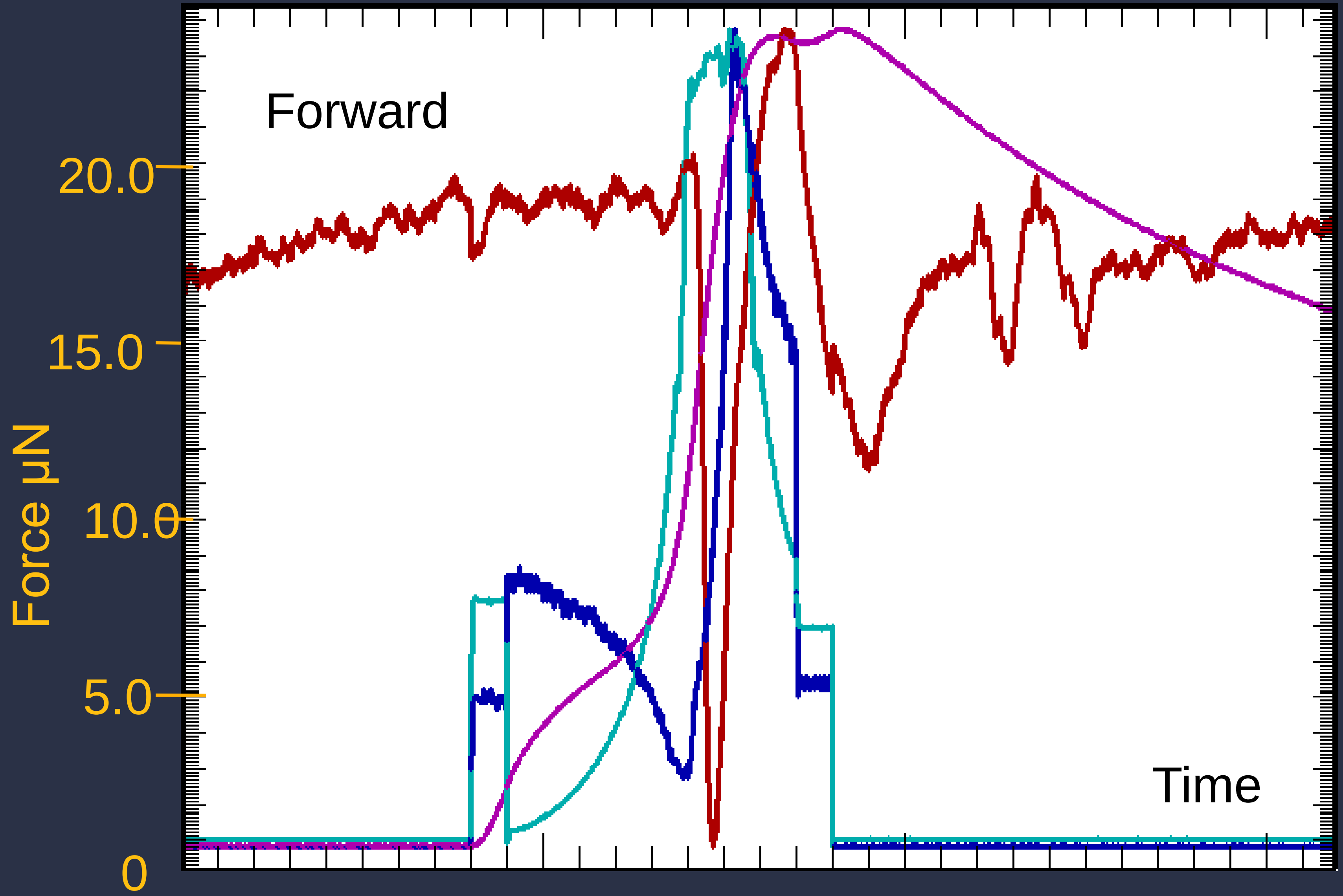
The liquid metal galinstan contacts used in the power circuit mounted coaxially above the flexural bearings that support the balance beam. The leads from the contacts to the connector block on the beam are braid shielded, and the leads to the test device from that point are shielded as they pass through the aluminum channel that forms the arm of the balance beam.

Experimental protocol:

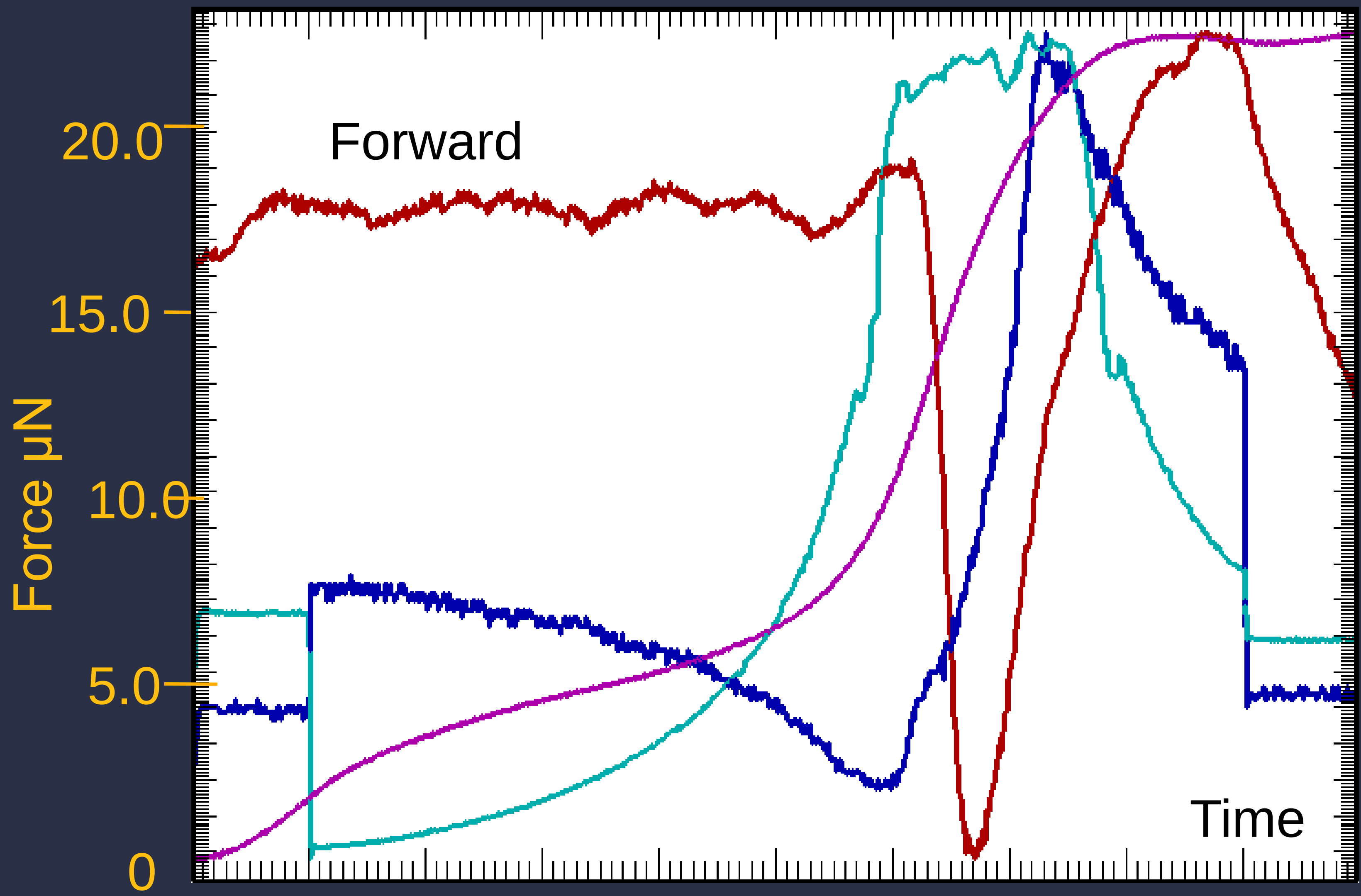
* Observable thrusts are only produced when the frequency of the driving signal is on a resonance of the device.
* During a cycle when data was acquired, a pulse of on resonance power was applied for a second or two, followed by a sweep of the frequencies above and below the resonance, followed by another on resonance pulse of a second or two's duration.
* In addition to the thrust recorded by the optical position sensor, we monitored, the voltage across the device ,the response of an accelerometer embedded in the PZT stack, and the temperature of the device.
* The test routinely done was reversal of the direction of the device on the end of the balance beam. Non-reversing thrusts – all assumed spurious – were eliminated by subtraction of the signals produced in the different directions.

Summer 2012

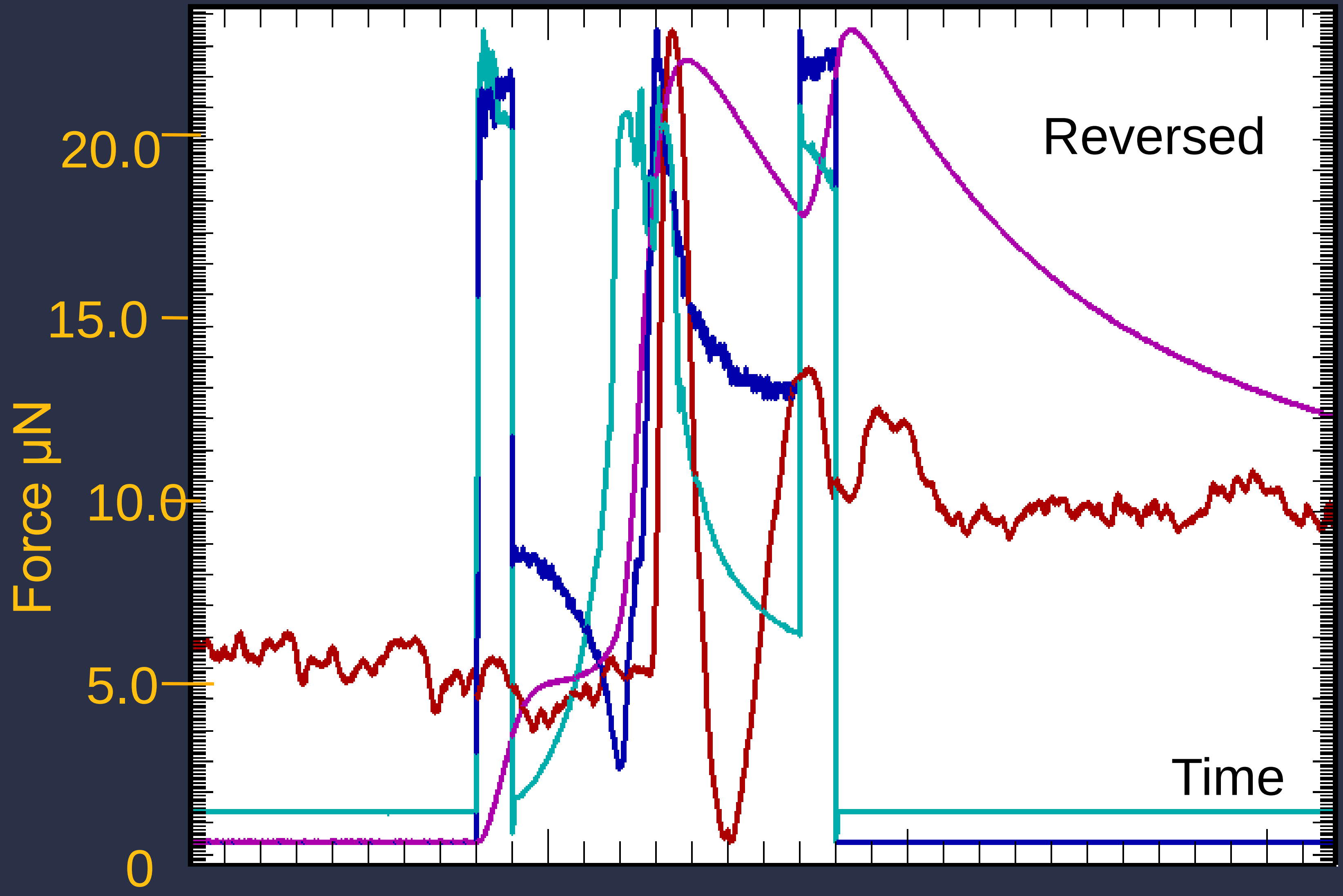
EARLY “SPECTACULAR” RESULTS OBTAINED IN “JUST SO” CONDITIONS



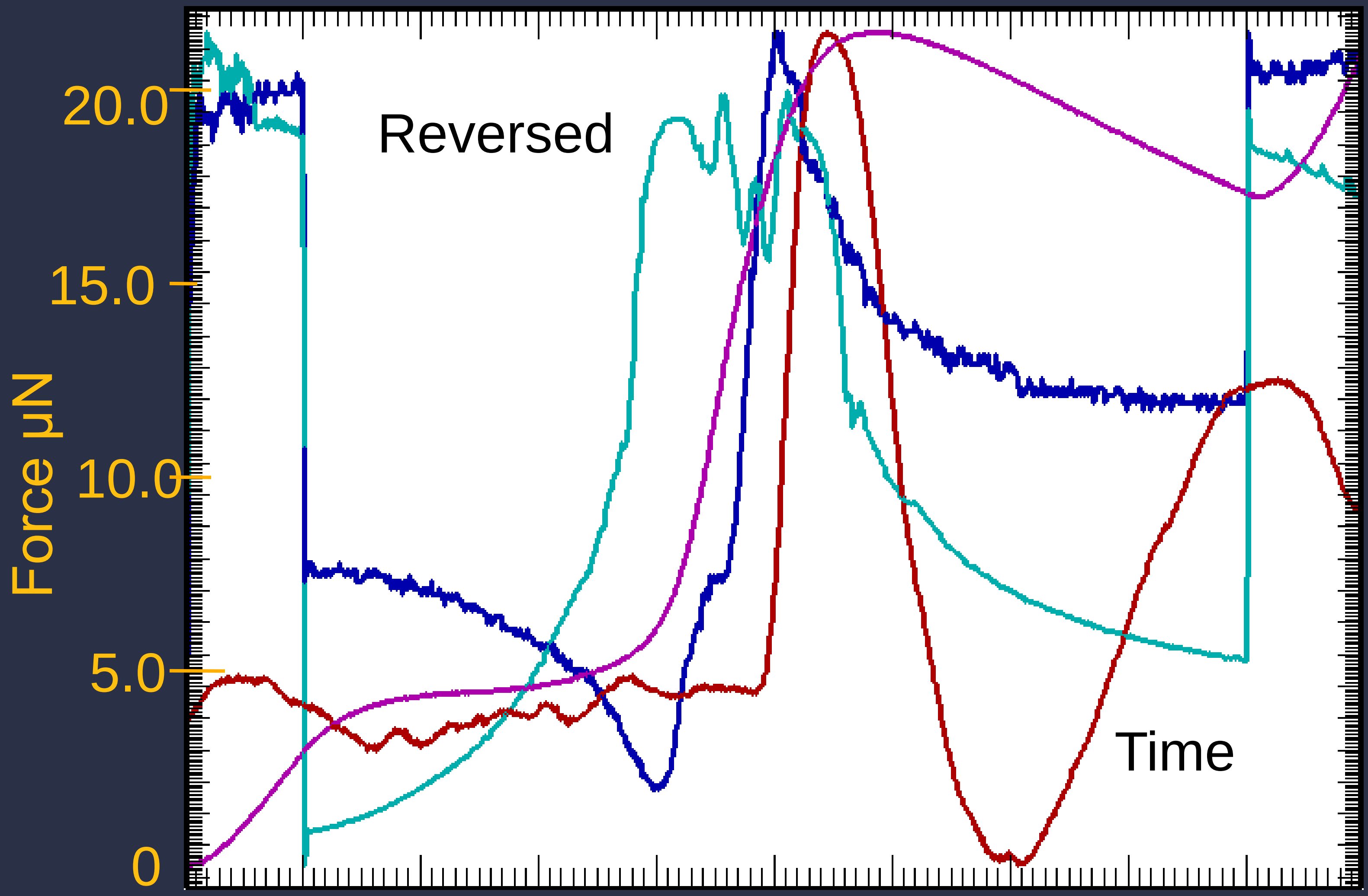
Run 1 with temperature trace added to display thermal evolution during powered interval. Note that the center frequency of the sweep is 35 KHz and the sweep range is 14 KHz. The peak of the (dark blue) power trace occurs at about 30.0 KHz.



Note that the onset of the spectacular behavior occurs when the temperature is changing at a constant rate (slope) where no thrust effect of thermal origins is expected. Single run SNR =12.=18/1.5



Run 1 with temperature trace added to show thermal evolution.



Note too that the thrust pulse is associated with the 30.0 KHz part of the power and accel. responses, whereas the first forward thrust pulse onset was associated with higher Frequency parts of the sweep.

ARE THE RESULTS IN THE PREVIOUS SLIDES EVIDENCE FOR A REAL EFFECT?

YES!

Di-lithium crystals?
No PZT or PMN !

Experimental Conclusions:

* The experimental results suggest that Mach effects actually exist, and,
* The detected thrusts are to better than order of magnitude the same as those predicted when the explicit acceleration dependent formalism is used.
* The experimental program will be directed to scaling the thrust effect to larger values, eventually to commercial levels.
* From the theoretical point of view, . . .

Theoretical Conclusions

Einstein believed in Mach's principle in 1918 and listed it on equal footing with his first 2 principles of relativity;

(1) The principle of relativity as expressed by general covariance
(2) The principle of equivalence
(3) Mach's principle (the first time this term entered the literature). . . . that the $g_{\mu\nu}$ are completely determined by the mass of bodies, more generally by $T_{\mu\nu}$.

In 1922, Einstein noted that others were satisfied to proceed without this [third] criterion and added,

"This contentedness will appear incomprehensible to a later generation however".

Einstein's prediction has not yet been realized. But we're working on it.

References:

[1] Sciama, D. W. “On the origins of Inertia”, Monthly notices of the Royal Astronomical Society, Vol. 113, 1953 pp 34-42.

[2] Nordvedt, K. “Existence of the gravitomagnetic interaction”, “ International journal of theoretical physics, Vol. 27, 1988 pp 1395-1404.

[3] Sultana, J. and Kazanas, D. “The problem of inertia in Friedmann Universe”, 2011, arXiv: 1104.1306v.
{when you multiply the Sciama result by 4, as Nordvedt [2] corrected Sciama’s work, the FW metric gives value F=0.92ma rather than F = 0.23ma, Which is very close to unity considering you are summing over the known causal universe! }

[4] Cook, R. J. “Is Gravitation a Result of Mach’s Inertial Interaction?”, Il Nuovo Cimento vol 35.,25 (1976). { Gives the known radius of the universe.. Equiv. of inertial and gravitational forces consequence of Mach’s principle.. And is the basis for the principle of equivalence in GR! Mach’s principle makes this implicit not an “add on”. }

[5] Fearn, H. and Woodward, J. "Recent Results of an Investigation of Mach Effect Thrusters" American Institute of Aeronautics and Astronautics, JCP conference (2012). See also 20 years of Woodward's work. [10-15]

[6] Pascual-Sanchez, J-F. "The harmonic gauge condition in the gravitomagnetic equations" arXiv: gr-qc/0010075v1

[7] Will, C. M., and Nordtvedt, K., "Conservation laws and preferred frames in relativistic gravity. I. Preferred-frame theories and an extended PPN formalism." The Astrophysical Journal Vol. 177, pp757-774 (1972).

[8] Brans, C. H. "Mach's Principle and the locally measured gravitational constant in General Relativity" Phys Rev 125, p388 (1962).

[9] Bondi , H. and Samuel J. "The Lense Thirring effect and Mach's Principle" Phys Letts A.228, pp121-126 (1997). {yes they are consistent}

[10] Misner, Thorne and Wheeler, "Gravitation" p546 regarding Mach's principle. {Many "trendy" GR text books don't even mention Mach's principle any more!}

PPN = Parametrized Post Newtonian approximation.

Extended or Modified PPN refers to when you take the flat space-time metric and Lorentz transform it into a frame with uniform velocity. See [2 and 6-7].

Jim Woodward's work:

10. “Making the Universe Safe for Historians: Time Travel and the Laws of Physics”, *Foundations of Physics Letters* **6**, 1 – 39 (1995). (called the MUSH paper.)

11. “Killing Time”, *Foundations of Physics Letters* **9,** 1 – 23 (1996).

12. “Twists of Fate: Can We Make Traversable Wormholes in Spacetime?”, *Foundations of Physics Letters* **10**, 153 – 181 (1997).

13. “Are the Past and Future Really Out There?” *Annales de la Fondation Louis de Broglie* **28**, 549 – 568 (2003).

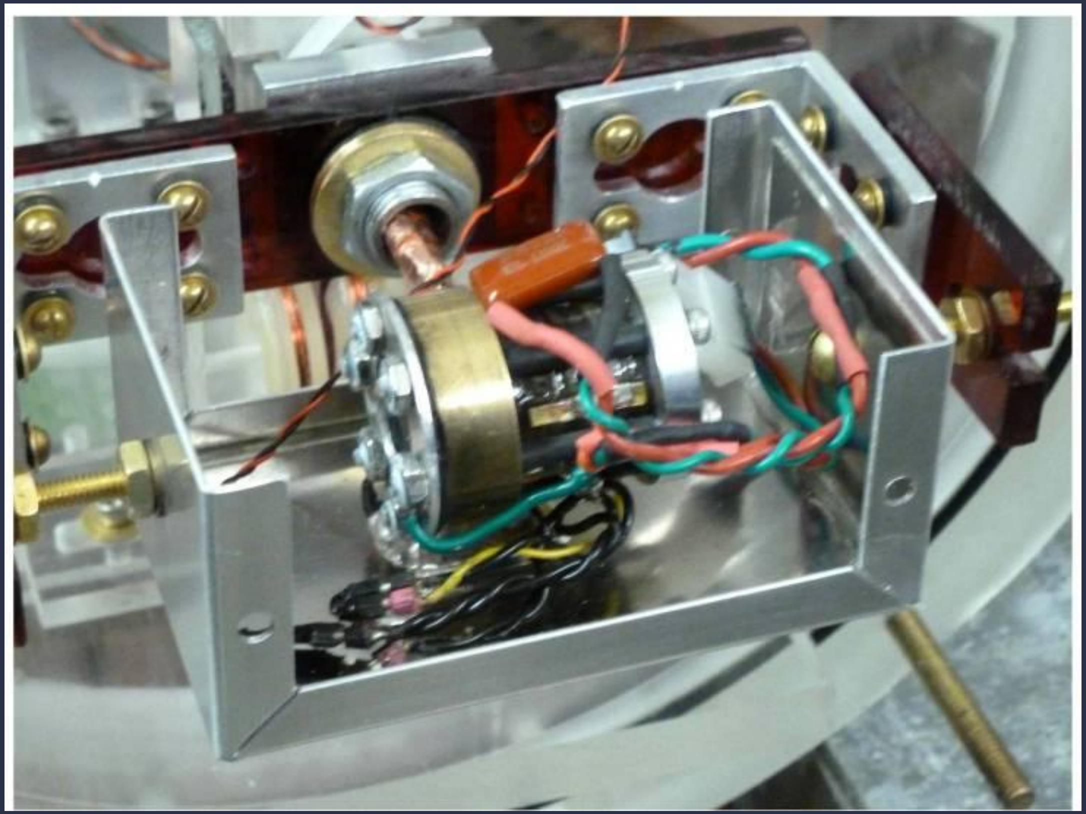
14. “Flux Capacitors and the Origin of Inertia”. *Foundations of Physics* **34**, pp1475 – 1514 (2004). (Derivation of mathematics in the Appendix)

15. “Making Stargates: the Physics of Traversable Absurdly Benign Wormholes”, *Physics Procedia* (proceedings of SPESIF 2011, 1 October 2011).

Appendix: Tests of the system:

- TO GO TO A SLIDE, SIMPLY PRESS THE NUMBER & hit “ENTER”

Emulation of the electrical performance using a dummy capacitor.



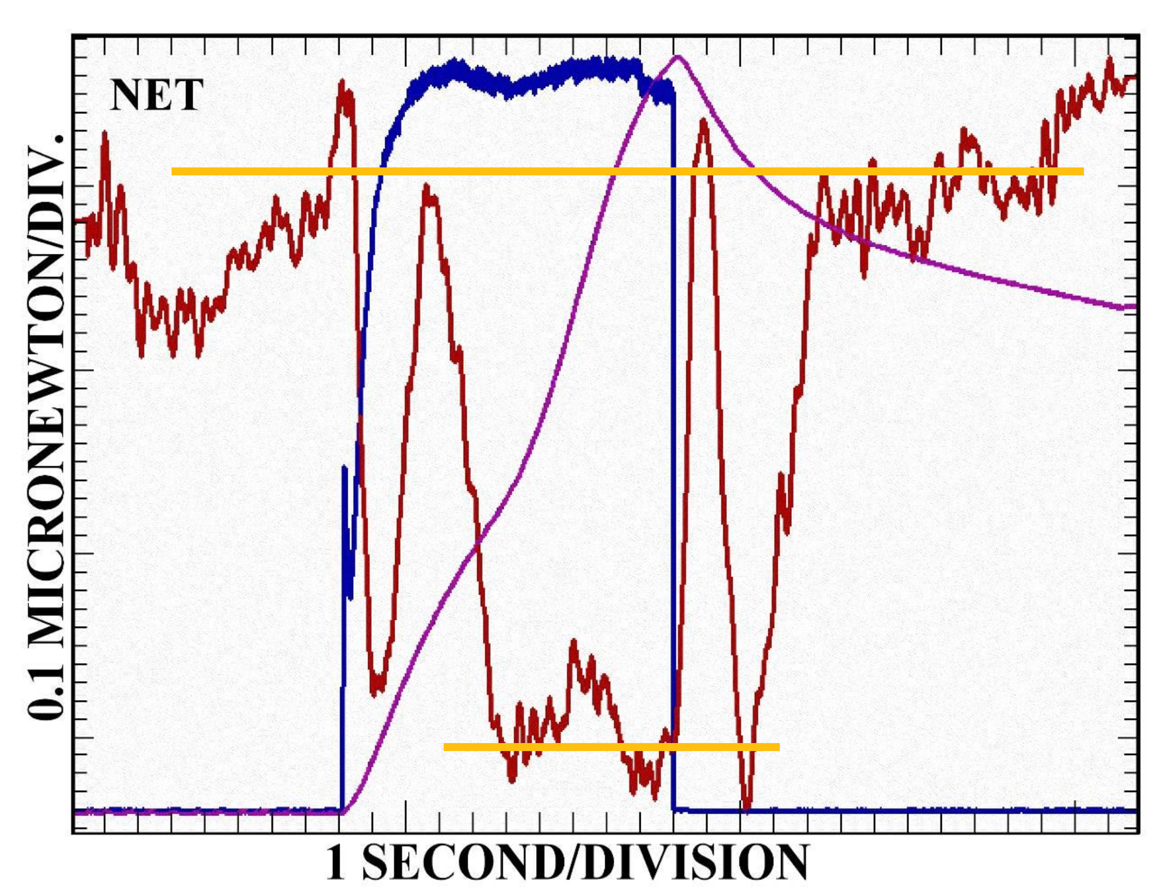
The dummy capacitor attached to the power feed and located in the Faraday Cage so as to emulate the currents present when the PZT devices are run. No thrust observed.

The mounted device with the top half of the Faraday cage removed to show the interior detail in the four orientations used in the direction dependence test.

Thermal Effects:

Qualitatively, the spectacular thrusts of the previous slides are hard to discriminate from thermal effects, for when the *rate* at which heating takes place in the device changes quickly, the *rate* of thermal expansion of the device also changes, and this can produce a thrust on the balance beam.

Steady heating and expansion do not produce a force on the beam, for the expansion proceeds at constant velocity.



The net of the forward and reversed results for the 10 second power pulse showing the stationary thrust during the last 5 seconds of the pulse after the power on transients have subsided. The powered and unpowered thrusts are emphasized with orange lines for ease of interpretation. While there is some small variation of the heating rate measured in the aluminum cap during the 10 second powered interval, it is orders of magnitude too small to account for the stationary thrust seen in these results. Allowing for linear power scaling, this thrust is consistent with the spectacular thrust obtained with the first device in January.

DEAN DRIVE EFFECT:

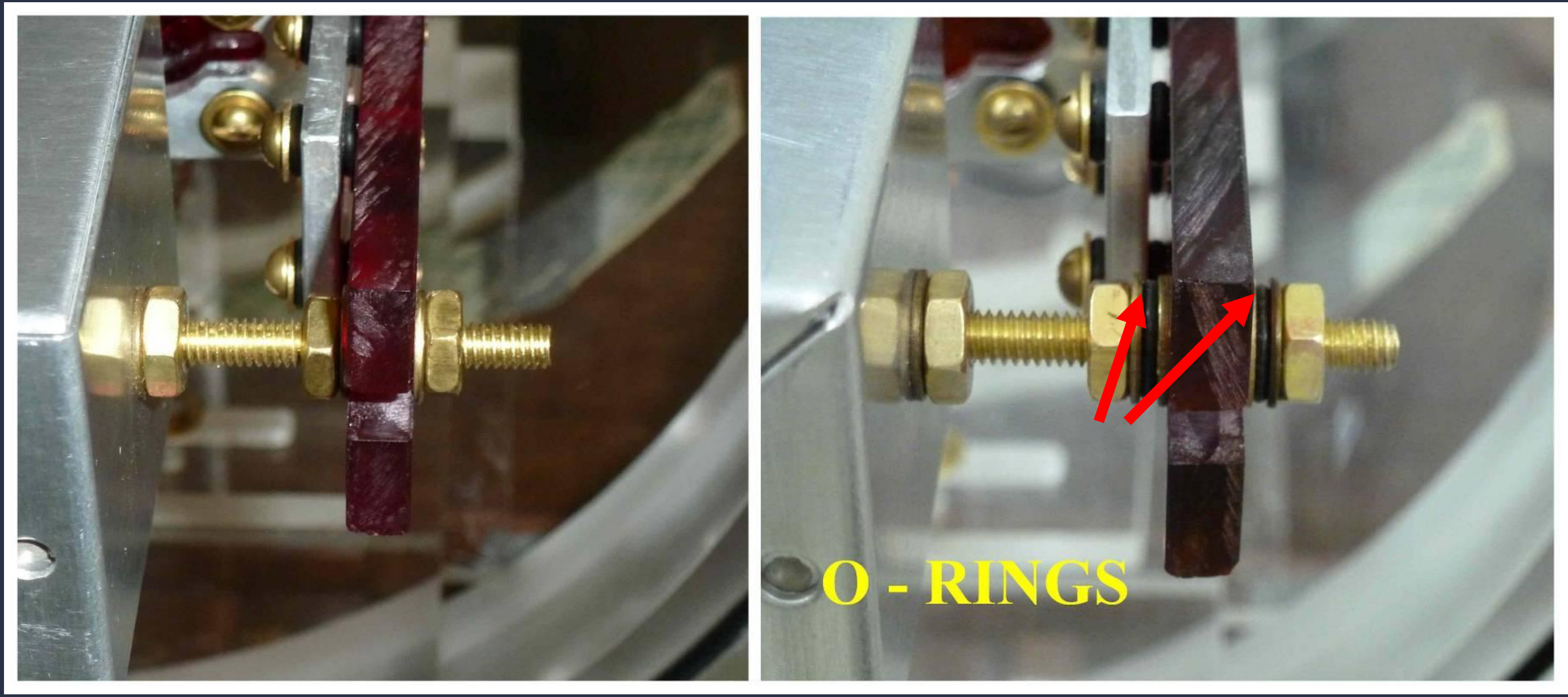
Earlier work showed no appreciable change in the thrust signals when all of the vibrations damping was removed, indicating that the thrust signals are not attributable to a Dean drive effect.
That conclusion is further supported by the response of the accelerometers fixed to the central balance beam support column and the collection of data for full vibration isolation, and when part of the isolation measures were removed.

Vibration Isolation:

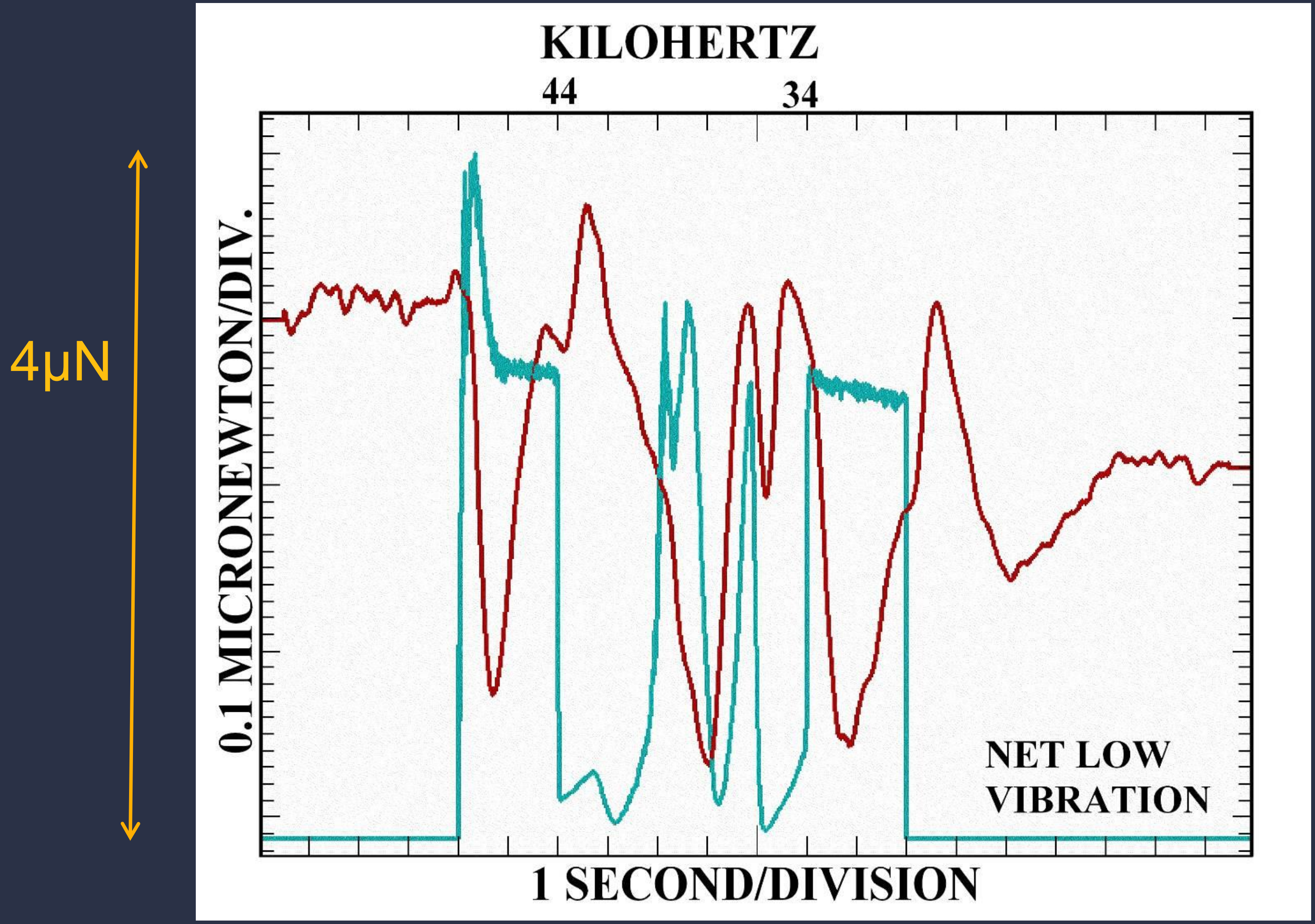
Mechanical systems with vibration can often produce curious effects. They usually arise from parts of the system where both static and dynamical friction operate to produce motion in some direction. In this system, the vibration produced during the operation of the devices might act on the bearings that support the balance beam, and that vibration might cause the beam to move.

Several tests for the effects of vibration were conducted. The results were all negative, the following test being typical.

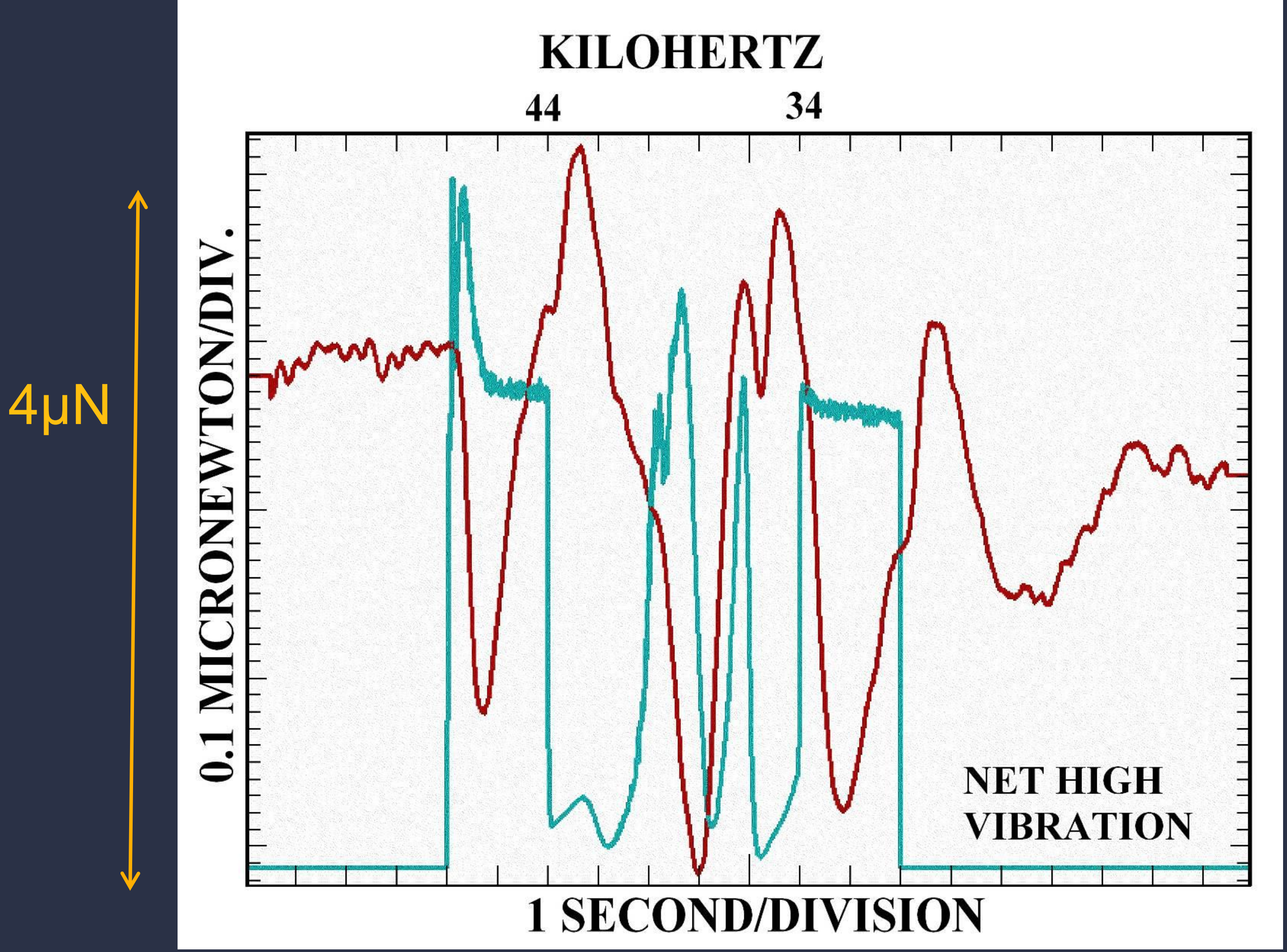
Variation of the vibration isolation:



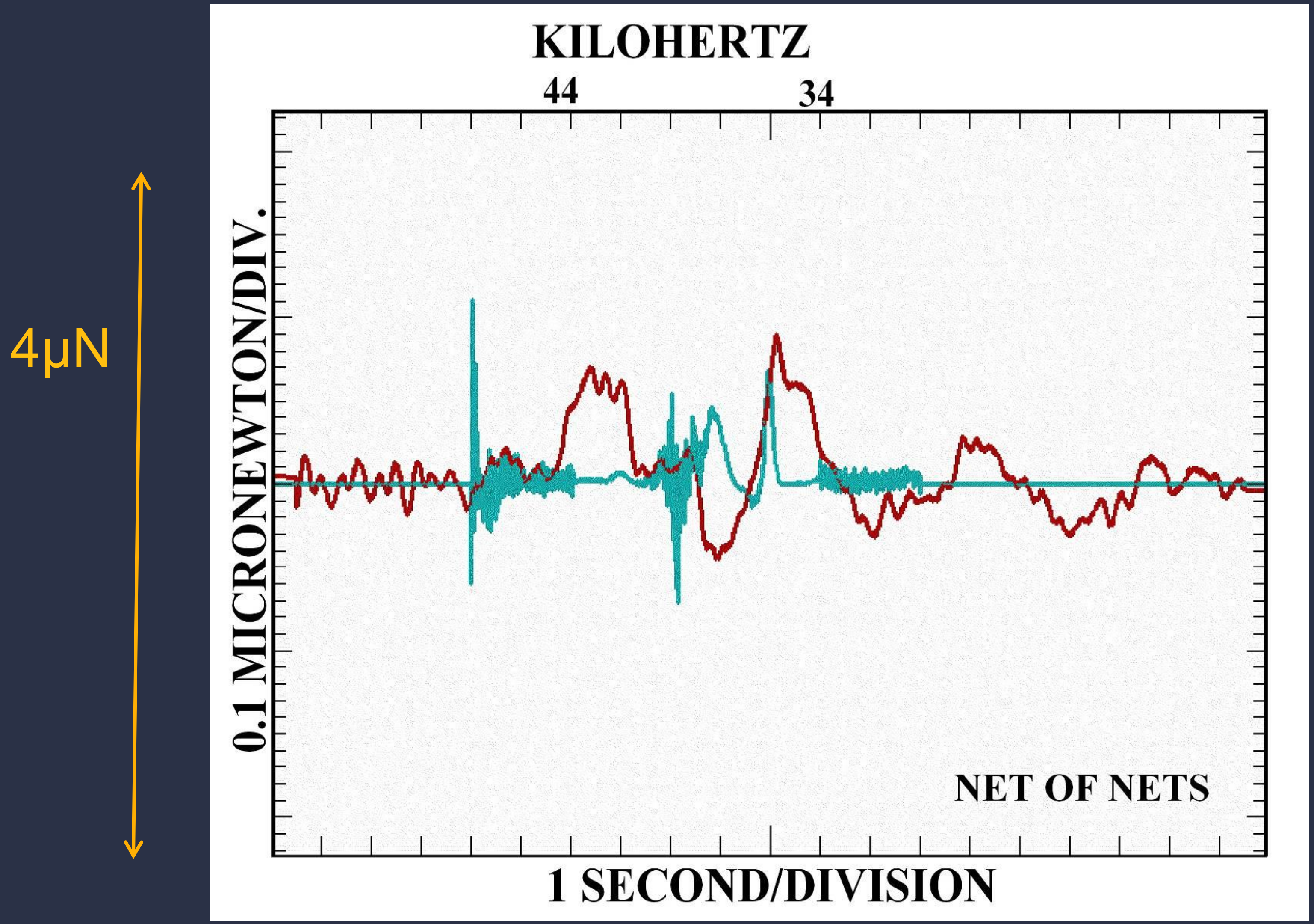
The two configurations of the mounting bolt attachment to the (dark red) plastic fork on the end of the balance beam. On the right the rubber O – rings normally present to attenuate vibration are indicated by the red arrows. On the left, the O – rings have been removed. The O – rings reduce the vibration reaching the center support column of the balance by 25%. But this had no effect on the thrust detected with the balance.



The net thrust signal obtained with full vibration isolation. Pronounced thrust signals are seen both in the constant center frequency pulses before and after the sweep, and for both of the resonances during the sweep. 4μN full scale.



The net thrust trace for the increased vibration.



The net of the nets with the results scaled so that the effective power in all cases was the same (the blue trace in the pre and post sweep pulses is zero). Slop in getting the center frequency exactly right leaves an uncancelled signal in the middle of the sweep, so the thrust cancellation as the resonances are swept is not exact. But no Dean drive signal appears in these results.